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Enhanced Hair Removal based on the "Avalanche Effect" of the AvalancheLase® Hair Removal Laser System

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ABSTRACT

The "avalanche effect," in which the absorption of laser light in hair is increasingly enhanced following each successively delivered laser pulse, was measured for two laser hair removal wavelengths, alexandrite (755 nm) and Nd:YAG (1064 nm).

Based on the results of the study, an "avalanche" laser hair removal protocol was developed for the alexandrite and Nd:YAG laser wavelengths of the AvalancheLase® hair removal system, which is equipped with novel DMC™ (Dry Molecular spray Cooling) skin-cooling technology.

In conclusion, the measured avalanche effect enables the performance of very effective "avalanche" hair removal by delivering a series of relatively low fluence pulses to hair follicles.

Key words: hair removal, avalanche effect, alexandrite laser, Nd:YAG laser.

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I. INTRODUCTION

Excess or unwanted hair is a common problem affecting both genders. First introduced in the mid-1990's, laser hair removal has become an accepted treatment modality for patients seeking to reduce unwanted hair, and it has also been found to improve quality of life for many patients [1, 2]. The types of lasers currently in use for hair removal include alexandrite, neodymium: yttrium-aluminum-garnet (Nd:YAG) and diode [3-12].

While all skin types can be treated (given the appropriate laser), in general, the greater the difference in pigmentation between the skin and hair, the better the result. The darker an individual's skin becomes, the more melanin they have, so the skin begins to heat more with the application of the laser, potentially leading to pain and epidermal damage. Therefore, darker skinned individuals must be treated at lower fluence levels and often require more treatments to attain good hair reduction [14-17].

Another challenge involves patients whose hair contains low melanin content, resulting in low absorption of laser light in treated hair. For this reason, early hair removal techniques were based on infiltrating black carbon into hair ducts in order to increase the absorption of hair at the treatment laser's wavelength [18].

However, more recently, it has been proposed that the absorption of laser light in hair could be enhanced by the treatment laser light itself [19, 20]. An "avalanche" effect was observed where the absorption of the treated hair became increasingly enhanced following each subsequently delivered laser pulse.

This phenomenon has led to an improved, "avalanche" hair removal protocol that consists of delivering a series of laser pulses to the same skin area, with the laser pulse parameters being optimized for the maximal avalanche effect. This technique is different from a standard "stamping" technique where the laser handpiece is positioned over the treated skin from spot to spot without any overlapping, and single high fluence pulses are delivered to each of the spots [7, 12].

In this paper, we study the avalanche effect by measuring hair temperature changes during the avalanche hair removal pulse series modality of an AvalancheLase® laser system that is capable of delivering extremely powerful and controlled outputs at alexandrite (755 nm) and Nd:YAG (1064 nm) wavelengths, and utilizes a novel DMC™ (Dry Molecular spray Cooling) skin-cooling technology.

II. MATERIALS AND METHODS

a) Laser system

The laser system used in the study was an

AvalancheLase® (manufactured by Fotona d.o.o., Slovenia; see Fig. 1) consisting of two ultra-performance solid crystal laser sources delivering two highly effective and well-known hair removal laser wavelengths, the Alexandrite (755 nm) and Nd:YAG (1064 nm) wavelengths. The system can be fitted either with an R35 manual handpiece (with 2-30 mm spot sizes) or an LX-Runner scanning handpiece (with individual spot size diameters of 9 and 11 mm, and an adjustable scan area of up to approximately 8 x 8 cm^2).

Fig. 1: AvalancheLase® alexandrite and Nd:YAG laser system.

In addition, AvalancheLase® is equipped with a novel proprietary DMC™ (Dry Molecular spray Cooling) technology integrated into the handpieces to allow for very fast, effective and non-contact cooling of the irradiated skin using a controlled very fine ("dry") water spray mist. This technology improves comfort and safety since it uses room temperature air and water, avoiding the risk of cryo-injury by over-cooling the skin [25].

b) Hair temperature measurements

The experimental set-up is shown in Fig. 2.

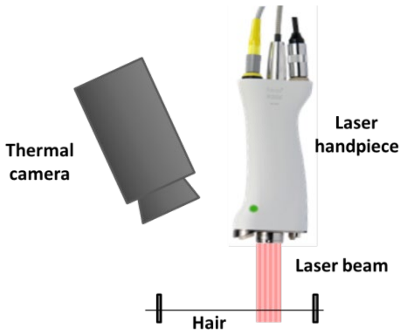

Fig. 2: Experimental set-up. A human hair was pulled out of a human scalp, and fixed in the air in a straight horizontal position. The Nd:YAG or alexandrite laser beam was directed onto the hair, and the resulting hair temperature increase was measured with a thermal video camera.

The Nd:YAG or alexandrite individual laser pulses (t_p = 2 ms) were directed onto the hair, and the resulting hair temperature increase following each laser pulse was measured with a thermal video camera (Flir ThermaCAM P45), set to record the maximal pump temperature increase (ΔT) of the hair sample. A room temperature air blower was used to shorten the hair cooling time following pulsed irradiation. The pulses were delivered at sufficiently long separation times ($t_s \geq$ 2 s) to allow the hair to cool down to the ambient temperature in-between pulses.

A typical thermal image of the irradiated hair following a laser pulse is shown in Fig. 3.

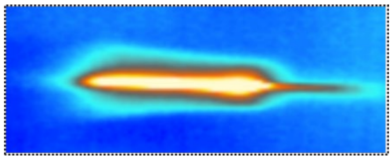

Fig. 3: A typical thermal image of the irradiated hair following a laser pulse.

c) Skin temperature measurements

In order to study how the skin temperature increase may limit the maximal laser pulse repetition rates during avalanche hair removal, the temporal evolution of the superficial skin temperature following a single Nd:YAG or an alexandrite laser pulse was also measured. Measurements were made for conditions without external skin cooling, and as well with DMC™ and cold air cooling.

III. RESULTS

a) Hair temperature results

Fig 4 shows the evolution of temperatures as observed by applying a series of individual Nd:YAG laser pulses to the same hair section with consecutively increased fluence (F_p) from F_p = 5 J/cm^2 up to F_p = 25 J/cm^2.

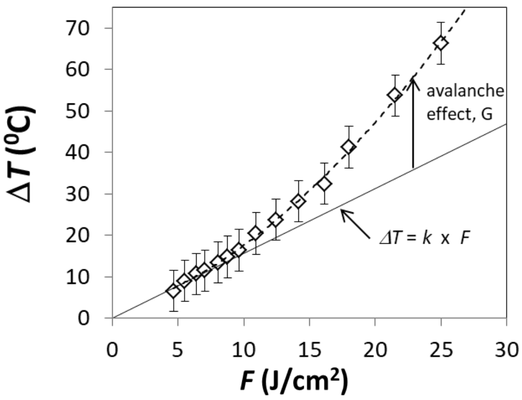

Fig. 4: Temperature increase ΔT of the same hair section following a series of individual Nd:YAG laser pulses with consecutively increased fluence. The pulses were delivered at sufficiently long separation times to allow the hair to cool down in-between pulses.

The line in Fig. 4 represents the linear dependence of the temperature increase on the delivered fluence according to:

$$\Delta T_{lin} = K \text{ x } F \,, \qquad (1)$$

as would be expected if there was no influence of laser irradiation on the hair's thermal characteristics. The temperature coefficient K (with K_{Nd} = 1.56 ^{0}C.cm^2/J) defines the linear growth of ΔT with F as observed at low laser fluences.

We attribute the observed deviation of ΔT from the linear dependence of Eq. 1 to the "avalanche" effect, i.e. to the increased thermal response of the human hair after being irradiated by a laser pulse with $F > F_a$, where F_a is the threshold fluence for the avalanche effect. For the used Nd:YAG laser parameters and the measured hair, the avalanche threshold was found to be at about $F_a \approx 10$ J/cm^2. Similarly, for the alexandrite laser we determined the avalanche threshold to be at about $F_a \approx 3$ J/cm^2.

Taking the avalanche effect into account, the dependence of the temperature increase on the delivered fluence can be expressed as:

$$\Delta T = G_a \text{ x } \Delta T_{lin} = G_a \text{ x } K \text{ x } F \,, \qquad (2)$$

where G_a is the "avalanche gain", characterizing the influence of the avalanche effect on the measured hair's thermal response. The total temperature increase is therefore represented by the sum $\Delta T = \Delta T_{lin} + \Delta T_a$, where $\Delta T_a = (G_a - 1) \text{ x } \Delta T_{lin}$ is the additional temperature increase caused by the avalanche effect.

Figure 5 shows the evolution of temperatures during the delivery of a series of N = 50 Nd:YAG or alexandrite laser pulses with the fluences (F) of 14.4 J/cm^2 (for Nd:YAG) and 5 J/cm^2 (for alexandrite) set to be just above the corresponding avalanche threshold values.

As can be seen from Fig. 6, the initial avalanche gain as observed for the first pulse in the sequence becomes significantly further enhanced during the first 20-30 pulses in the series.

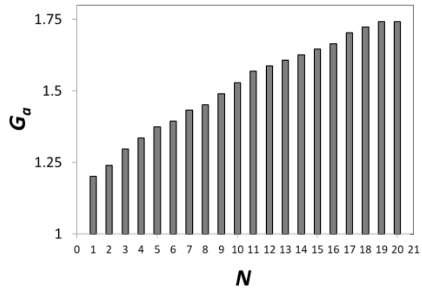

Fig. 6: Gradual increase of the avalanche gain G_a during the delivery of Nd:YAG pulses from Fig. 5a.

b) b) Skin temperature results

Figure 7 shows the measured skin temperature evolution following a single Nd:YAG or an alexandrite laser pulse when no external cooling was used. The observed initial fast decay is caused by the large temperature gradient between the melanin-rich epidermis and the deeper-lying dermis. As expected, the decay is faster for Nd:YAG due to the larger initial temperature difference between the epidermis and dermis. Therefore, the avalanche repetition rates can be faster when using an Nd:YAG laser.

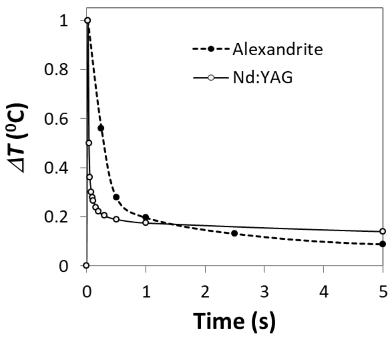

Fig. 7: Temperature evolution following a single Nd:YAG or alexandrite laser pulse when no external skin cooling is used.

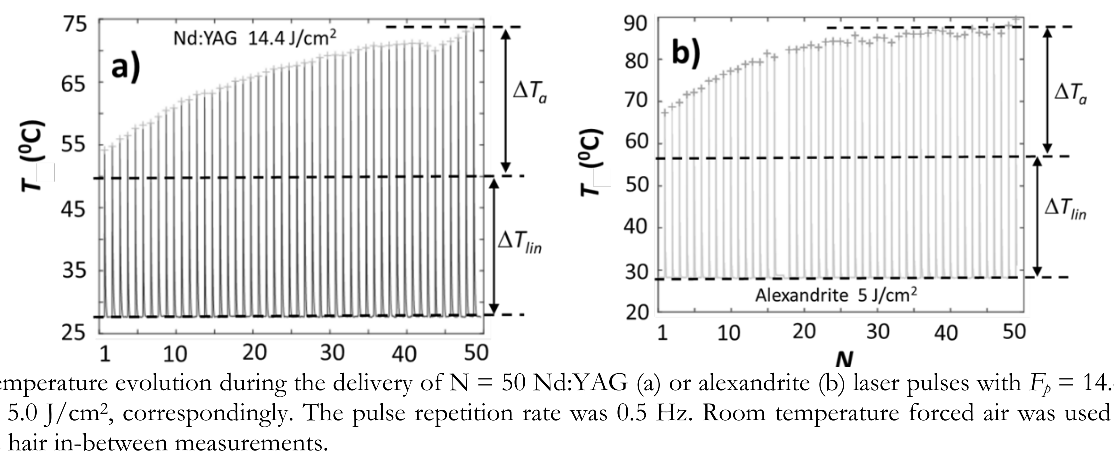

Fig. 5: Temperature evolution during the delivery of N = 50 Nd:YAG (a) or alexandrite (b) laser pulses with F_p = 14.4 J/cm^2 and F_p = 5.0 J/cm^2, correspondingly. The pulse repetition rate was 0.5 Hz. Room temperature forced air was used to cool down the hair in-between measurements.

Figure 8 shows the measured skin cooling rate of non-irradiated skin during cold-air and DMC™ cooling.

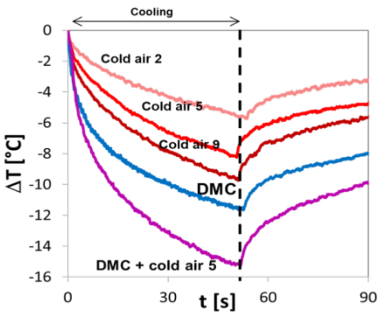

Fig. 8: Comparison of the DMC™ cooling characteristic with that of the standard cold-air cooling.

As can be seen from Fig. 8, the DMC™ cooling technology delivers fast cooling rates, enabling fast and comfortable non-contact avalanche hair removal on all body areas.

IV. DISCUSSION

Our measurements demonstrate an avalanche effect which occurs when hair is subjected to an individual laser pulse of a sufficiently high fluence, or to a series of lower fluence laser pulses. This effect leads to an enhancement of the temperature response of the irradiated hair.

Based on the results of our study, laser hair removal treatment can be performed at laser fluences much lower than what is required when performing hair removal using the stamping technique [7, 12, 14]. By repeating the treatment irradiation within the same treatment session, the effect of each treatment irradiation is enhanced, until the hair removal temperatures within the hair follicle are reached.

A major limitation of the study is that temperature measurements were carried out on hair suspended in air, while in a clinical situation the hair is embedded within the skin matrix. Nevertheless, simulations of the hair temperature under Nd:YAG and alexandrite irradiation indicate that the observed avalanche phenomenon may apply also to hair located within the skin matrix. In a study by Žaneček and Milanič [24], a numerical model of laser epilation was developed, which also used experimentally obtained hair and skin parameters to calculate the temperature increase along the hair shaft down to the hair follicle. The temperatures of the hair located within the skin matrix were found to be similar or higher than those obtained for the hair suspended in air. This is due to the scattering of the laser light within the skin matrix, effectively enhancing the number of photons that become trapped within the highly absorbing hair, in spite of the beam being progressively absorbed by the skin chromophores.

Therefore, the hair temperatures under a clinical setting are expected to be above the avalanche threshold when using relatively low fluence values for the Nd:YAG and alexandrite laser epilation.

When performing hair removal based on the observed avalanche effect using a manual handpiece, the treatment is performed using a brushing technique. This technique involves higher pulse rates (3-5 Hz), with the R35 handpiece in a constant movement backwards and forwards at a speed of 2-3 cm/s until a sufficiently high cumulative energy is delivered to the whole treated area. So rather than lasing each hair follicle individually with a high powered beam, the avalanche technique accumulates the delivered energy into the entire treated area over a larger number (N) of lower-fluence pulses, to a point in which the hair follicles get damaged.

An example of the clinical efficacy of the avalanche hair removal technique is presented in Fig. 9, which shows the persistent avalanche hair removal effect four (4) months following only a single treatment with the alexandrite wavelength of the AvalancheLase® hair removal laser system.

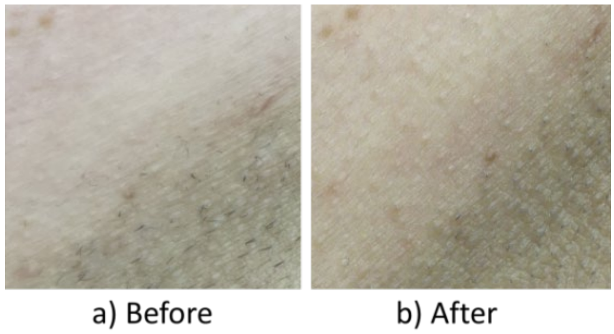

Fig. 9: Underarm hair removal a) before; and b) 4 months after a single avalanche treatment with alexandrite laser using the following parameters R35X handpiece, 10 Jcm², 3 Hz, 2 ms, 12 mm.

V. CONCLUSIONS

In conclusion, the measured avalanche effect enables the performance of very effective "avalanche" hair removal by delivering a series of relatively low fluence pulses to hair follicles. This characteristic, combined with the proprietary skin cooling DMC™ technology, enables fast, painless and very effective hair removal using the AvalancheLase® laser system.

Based on the carried out temperature measurements and clinical experience, the following treatment parameters are recommended for performing avalanche hair removal with the Alexandrite (Figure 10) and Nd:YAG laser (Figure 11), in conjunction with the AvalancheLase's DMC™ skin cooling technology. The parameters are given for different body areas, skin types (I-VI) and hair thicknesses (thin, medium and thick). The estimated number (N) of delivered avalanche pulses to the same follicle, and the estimated time (in minutes) required to treat the whole selected body area, are also provided.

Alexandrite (755 nm)						
Avalanche Hair Removal Parameters						
Body area	Fluence F_p (J/cm^2)	Spot size (mm)	Pulse duration (ms)	Freq (Hz)	N	Estimated total treatment time (min)
	I-II-III-IV-V-VI	I-VI	Thin-Medium-Thick	I-VI	I-VI	I-VI
Thigh	11-9-7-5-4-3	20	2 - 3 - 4	3	4-10	7-26
Lower leg	11-9-7-5-4-3	20	2 - 3 - 4	3	4-10	6-24
Chest & Abdomen	11-9-7-5-4-3	20	2 - 3 - 4	3	4-10	10-38
Underarm	11-9-7-5-4-3	12	2 - 3 - 4	5	4-10	1-2
Bikini	11-9-7-5-4-3	12	2 - 3 - 4	5	4-10	1-4
Face	11-9-7-5-4-3	12	2 - 3 - 4	5	4-10	0.5-1.5
Back	11-9-7-5-4-3	20	2 - 3 - 4	3	4-10	9-32

Fig. 10: Recommended avalanche hair removal parameters for the alexandrite (755 nm) laser wavelength of the AvalancheLase® system, equipped with an R35X laser handpiece and DMC™ skin cooling technology (water 1-2, air 5).

Nd:YAG (1064 nm)						
Avalanche Hair Removal Parameters						
Body area	Fluence F_p (J/cm^2)	Spot size (mm)	Pulse duration (ms)	Freq (Hz)	N	Estimated total treatment time (min)
	I-II-III-IV-V-VI	I-III, IV-VI	Thin-Medium-Thick	I-VI	I-VI	I-VI
Thigh	22-18-14-10-8-6	12,20	2 - 3 - 4	3	4-15	13-29
Lower leg	22-18-14-10-8-6	12,20	2 - 3 - 4	3	4-15	12-26
Chest & Abdomen	22-18-14-10-8-6	12,20	2 - 3 - 4	3	4-15	19-42
Underarm	22-18-14-10-8-6	12	2 - 3 - 4	5	4-15	1-2.5
Bikini	22-18-14-10-8-6	12	2 - 3 - 4	5	4-15	1.5-4.5
Face	22-18-14-10-8-6	12	2 - 3 - 4	5	4-15	0.5-1.5
Back	22-18-14-10-8-6	12,20	2 - 3 - 4	3	4-15	16-36

Fig. 11: Recommended avalanche hair removal parameters for the Nd:YAG (1064 nm) laser wavelength of the AvalancheLase® system equipped with an R35X laser handpiece and DMC™ skin cooling technology (water 1-2, air 5)

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